NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 04-91

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An understanding of the objective and subjective symptoms of hypoxia is deemed necessary to both aviators and divers to avoid mishaps resulting from a decreased partial pressure of oxygen (PO_2). Current DOD hypobaric training profiles place aviator students at risk for decompression sickness (DCS). Despite recent efforts to minimize the potential for DCS, the incidence of hypobaric induced DCS remains undiminished. The purpose of this study was to identify an oxygen-nitrogen gas mixture for use as an alternative method of inducing hypoxia in subjects at 1 ATA during naval aviation physiology training. Students could then be indoctrinated to the symptoms of hypoxia without being exposed to the risk of DCS. Twelve subjects, Navy divers from 25 to 48 years of age participated in this study. Six different nitrogen-oxygen gas mixtures were used. Three were selected to include and bracket a PO_2

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value of 7% which, by calculation, approximately equals the Navy physiology training altitude. These three were 93.80% N_2, 6.20% O_2; 93.00% N_2, 7.00% O_2, and 92.15% N_2, 7.85% O_2. Two mixtures were selected which were of interest to the Navy diving community: 88.16% N_2, 11.84% O_2 and 85.86% N_2, 14.14% O_2. The sixth gas mixture was air (79.15% N_2, 20.85% O_2) and was used as a control. A two-dimensional compensatory tracking task was used to test cognitive function of each subject while breathing a test mixture. Physiological monitoring included heart rate, ECG, end-tidal carbon dioxide, oxygen saturation, and blood pressure. The six gas mixtures were administered using a double blind experimental design. The 93.80% N_2, 6.20% O_2 gas mixture was determined to have practical application for use as an alternative method of inducing hypoxia during aviation physiology training. It induced a significant level of hypoxia in a relatively short period of time which subjects quickly and completely recovered without evidence of serious health risks.

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I. INTRODUCTION

An understanding of the objective and subjective symptoms of hypoxia is deemed necessary to both aviators and divers to avoid mishaps resulting from a decreased partial pressure of oxygen (PO_2). Navy aircrewmen are presently trained in hypobaric chambers at a simulated altitude of 25,000 feet to recognize the symptoms of hypoxia and take appropriate corrective action (OPNAVINST 3710.7M). Divers are trained to determine proper gas mixtures for use at depth with mixed gas systems, thus preventing hypoxia.

Current DOD hypobaric training profiles place students at risk for decompression sickness (DCS). Historically, the combined incidence of DCS resulting from Navy training for both students and medical attendants working inside hypobaric chambers has averaged 0.099% or approximately one DCS out of every 1,000 people participating in decompression chamber training [1]. Recent efforts to minimize the potential for DCS are: (a) denying chamber exposure to trainees who do not meet demanding medical screening requirements, (b) requiring 30 minutes of preoxygenation for the medical attendants to assist in denitrogenation, (c) requiring 100% oxygen usage throughout the chamber ascent and descent, (d) limiting the terminal altitude to 25,000 feet, and (e) discouraging excessive physical exercise prior to and after chamber exposure. Despite these efforts the incidence of hypobaric induced DCS has not diminished. From 1 October 1986 through 30 June 1989, the combined incidence of DCS for both students and medical attendants involved in aviation physiology training conducted at the Naval Aerospace Medical Institute was 0.16%. The Navywide incidence of DCS for all students participating in aviation physiology training for CY 1988 was 0.15%.

Other investigators have successfully used oxygen-nitrogen gas mixtures to induce hypoxia in subjects at 1 atmosphere absolute (ATA) [2,3]. This practice totally eliminates the threat of DCS. The purpose of this study was to identify an oxygen-nitrogen gas mixture which would have practical application for use as an alternative method of inducing hypoxia during aviation physiology training. Students could then be introduced to the symptoms of hypoxia without being exposed to the risk of DCS. Benefits to the diving community would include prevention of diver hypoxia by reverification of established PO_2 limits for breathing gases.

II. METHODS

A. SUBJECTS

Twelve subjects, all qualified Navy divers, volunteered to participate in this study. Subjects ranged in age from 25 to 48 years. An informed consent was obtained from all subjects. Any subject could terminate, for whatever reason, upon request. The test plan was reviewed and approved by the Review Committee for the Protection of Diver-Subjects.

B. MASK AND REGULATOR

A standard Scott quick don smoke mask, Model 358, and two MD-CRU regulators were used to supply the test gas mixes and the recovery gas (100% oxygen) to each subject. The MD-CRU regulator is a demand regulator and is the standard regulator presently used in all Navy low pressure chambers where aviation physiology training is conducted. The Scott quick don mask covers only the subject's nose and mouth. Test subject vision is not affected. The mask hose was connected to a "Y" fitting, each side of which was connected by a hose to one of the MD-CRU regulators. One regulator supplied the test gas while the other supplied 100% oxygen. A valve was placed in the 100% oxygen hose and was closed while the subject received the test gas. For recovery this was opened to supply 100% oxygen to the subject.

The mask was modified to accept a capillary tube for breath-to-breath gas analysis.

C. GAS MIXTURES

Six premixed bottles, each containing a different nitrogen-oxygen gas mixture, made up the experimental gas bank. Three mixtures were selected to include and bracket an P_IO_2 value of 7% which by calculation approximately equals the physiology training altitude of 25,000 feet. These mixtures were: 93.80%N_2, 6.20%O_2; 93.00%N_2, 7.00%O_2 and 92.15%N_2, 7.85%O_2. Two mixtures were selected which were of interest to the Navy diving community. These helped to determine minimum oxygen percentages for gas mixtures which could safely but inadvertently be used at the surface. These mixtures

were 88.16%N_2, 11.84%O_2 and 85.86%N_2, 14.14%O_2. The sixth gas mixture was air (79.15%N_2, 20.85%O_2) and was used as a control.

D. COMPENSATORY TRACKING TASK

A two-dimensional compensatory tracking task which is a candidate for the Unified Triservice Cognitive Performance Assessment Battery (UTC-PAB) was used to test cognitive function of each subject while breathing the mixed gas. The task was run on a Zenith 248 computer and required the subject to use his preferred hand to manipulate a joystick to move a cross onto a fixed center point displayed on a monitor. The computer would not permit passive holding of the cross on the center point, therefore the subject was required to constantly readjust the cross. This task was modified to run in a test cycle of 65 seconds. A 10-second rest cycle followed each 65-second tracking cycle. The first 5 seconds of the tracking cycle were discarded as contaminated data. The remaining 60 seconds were scored in 15-second intervals as to how near the center the cross was held. Deviation from the center point caused number accumulation. A perfect score would be 0.

Since this method of scoring did not lend itself to computing performance impairment with the onset of hypoxia, a reversed scoring procedure was developed for use in data analysis. This procedure took the maximum possible score which could be obtained with the test (cross located in corner of screen at maximum distance from center point for the entire 15-second interval) and subtracted the subject's score. Each subject's baseline performance score was the mean score obtained during the session using the control gas mixture. This was assumed to represent the 100% performance level for each subject and individual impairment scores for the experimental gas mixtures were computed as a function of this baseline performance level.

E. EXPERIMENTAL DESIGN

All subjects participated in three training sessions with the compensatory tracking task to eliminate the learning curve and improve performance stability during the experimental sessions. During one of these training sessions, each subject had the opportunity to wear the mask which was used during the experiment. This was done to familiarize them with the fit and feel of the mask prior to the beginning of formal data

collection. Each subject completed a total of five training sets with eight 65-second tracking cycles per set.

Each experimental gas mixture was randomly assigned a gas number from 1 to 6 for use during the experiment. The gases were administered in accordance with a pre-established schedule (Table 1). Each of the twelve subjects was randomly assigned to one of twelve subject positions in the schedule. The gas mixtures were administered over a three-day period, one gas in the morning and one gas in the afternoon with a minimum of four hours between test sessions. Neither the subject nor the investigator knew which mixture was being administered during any given test session thus establishing a double blind experimental design.

Each test session began by seating the subject in a chair facing the monitor upon which the tracking task would be displayed. After connecting the subject to physiological monitoring equipment, the subject donned the mask and adjusted it for comfort. Normal air was delivered to the subject during this hookup phase. The investigator then activated the computer, and the subject began tracking for one complete cycle (65 seconds) still breathing normal air. This first cycle on air permitted the subject to become comfortable with the tracking task and provided baseline information for that testing session. At the 5-second mark during the 10-second rest period following the first tracking cycle, the valve delivering the appropriate test gas for that session was opened and the valve delivering air was closed. This procedure ensured that the test gas had totally replaced all air in the hoses by the time the subject was five seconds into the second tracking cycle. At that point performance scoring began. The subject continued the tracking task while breathing the test gas until either the investigator terminated the test or the computer automatically stopped the test after eight tracking cycles. This limited the maximum exposure for any subject to any test gas to 600 seconds (8 tracking cycles X 65 sec + 8 resting periods X 10 sec = 600 sec). At termination, the investigator opened a valve which delivered 100% oxygen to the subject while simultaneously securing the valve delivering the test gas. Each subject was required to breathe 100% oxygen for a one-minute period following termination to facilitate recovery.

The investigator was a designated Naval Aerospace Physiologist experienced in recognizing objective symptoms of hypoxia as displayed by naval aircrew members undergoing low pressure chamber training. The investigator

TABLE 1

SUBJECT-GAS MATRIX

	Day 1		Day 2		Day 3	
Subject	AM Gas *	PM Gas *	AM Gas *	PM Gas *	AM Gas *	PM Gas *
1	1	2	3	4	5	6
2	2	3	4	5	6	1
3	3	4	5	6	1	2
4	4	5	6	1	2	3
5	5	6	1	2	3	4
6	6	1	2	3	4	5
7	1	2	3	4	5	6
8	2	3	4	5	6	1
9	3	4	5	6	1	2
10	4	5	6	1	2	3
11	5	6	1	2	3	4
12	6	1	2	3	4	5

terminated a test session when the subject either stopped moving the joystick and made no attempt to continue tracking or when the subject's movement of the joystick became totally ineffective in keeping the cross centered on the monitor. This termination point was considered to be at the very end of a subject's time of useful consciousness.

F. PHYSIOLOGICAL MONITORING

1. Heart Rate and Electrocardiogram (ECG)

A standard three-electrode ECG was used to monitor and record a Lead-II ECG for each subject.

2. Breath-to-Breath Exhaled Gas Analysis

End-tidal carbon dioxide and oxygen partial pressure ($P_{et}CO_2$,$P_{et}O_2$) were measured using a single capillary sampling tube placed in the oronasal cup 1-2 cm from the subject's lips. Gas analysis was done by mass spectrometers (Perkin Elmer, Model MGA 1100-turbo, Pomona, CA and/or Extrel Quester, Model I-M process analyzer, Pittsburg, PA). The output from the mass spectrometers was recorded on a strip chart recorder (Gould ES-2000). Accuracies of the mass spectrometers are reported to be: Perkin Elmer, $\pm$ 0.05% and Extrel, $\pm$ 0.005%.

Response time to 90% full signal of an introduced calibration gas by injection has been demonstrated at Naval Experimental Diving Unit to be 100-110 msec for the Perkin Elmer and 90-100 msec for the Extrel. Perkin Elmer reports a 90% response time to be 100 msec. Extrel does not document any response time to the introduction of a new gas, as in breath-to-breath studies. Calibration was conducted as required on a daily basis prior to experimentation.

3. Pulse Oximeter

A pulse oximeter (Nellcor N-200) was used to give a continuous, instantaneous reading of PO_2 by percent saturation. The sensing probe was taped to the tip of the subject's index finger on the hand not used in performing the tracking task.

4. Blood Pressure

A blood pressure cuff was used to measure each subject's blood pressure prior to the start of each testing session and during the one-minute recovery period following each testing session.

5. Hypoxia Symptom Questionnaire

Immediately following the one-minute recovery period breathing 100% O_2, each subject completed a questionnaire identifying any subjective symptoms of hypoxia experienced during the test session. A list of 15 symptoms appeared on the questionnaire. The subject was asked to indicate the severity of any symptom experienced using the following scale: not observed, mild, moderate, severe. The subject could write in symptoms not included in the list.

III. RESULTS

Test termination time is shown in Table 2. All twelve subjects breathing the 6.20% oxygen mixture had their test session terminated by the investigator and were unable to continue to the 600 second automatic stop point. Their mean time to termination was 293 seconds. Six subjects breathing 7.00% oxygen were terminated by the investigator, while five were terminated at the automatic stop point. Their mean time to termination was 518 seconds. Three subjects breathing 7.85% oxygen were terminated by the investigator while nine reached the automatic end point. Their mean time to termination was 591 seconds. All subjects breathing 11.84% O_2, 14.14% O_2, and 20.85% O_2 reached the automatic end point of 600 seconds. Some test sessions were missed by two of the subjects. This did not invalidate the study.

The subjective symptoms of hypoxia experienced by the subjects are reported in Table 3. As the percentage of oxygen in the test gas decreased the number and severity of symptoms reported increased as anticipated.

The tracking performance for subjects breathing 6.20% O_2, 7.00% O_2, and 7.85% O_2 are shown in Figures 1-3, respectively. The mean tracking performance scores at the time of test termination were 77% for the 7.85% O_2 mixture, 71% for the 7.00% O_2 mixture, and

TABLE 2

TIME TO TEST TERMINATION

Subject	6.20% O_2 n=12 (s)	7.00% O_2 n=11 (s)	7.85% O_2 n=12 (s)	11.84% O_2 n=10 (s)	14.14T O_2 n=10 (s)	20.85% O_2 n=12 (s)
1	252	*	600	*	*	600
2	256	600	600	*	*	600
3	161	331	600	600	600	600
4	248	478	600	600	600	60C
5	354	600	600	600	600	600
6	390	600	600	600	600	600
7	284	407	600	600	600	600
8	328	503	600	600	600	600
9	374	600	600	600	600	600
10	242	316	475	600	600	600
11	264	600	518	600	600	600
12	362	600	600	600	600	600
Mean	293	512	583	600	600	600

*Subject unavailable for testing for reasons not associated with study.

TABLE 3

SUBJECTIVE SYMPTOMS OF HYPOXIA

	6.20% O_2 n=12				7.00% O_2 n=11				7.85% O_2 n=12				11.84% O_2 n=10				14.14% O_2 n=10				20.85% O_2 n=12			
Subjective Symptoms From Questionnaire	Not Observed	Mild	Moderate	Severe	Not Observed	Mild	Moderate	Severe	Not Observed	Mild	Moderate	Severe	Not Observed	Mild	Moderate	Severe	Not Observed	Mild	Moderate	Severe	Not Observed	Mild	Moderate	Severe
Tingling	2	6	3	1	2	3	5	1	3	4	4	1	1	3	0	0	8	2	0	0	12	0	0	0
Hot Flashes	6	6	0	0	9	2	0	0	6	5	1	0	10	0	0	0	10	0	0	0	12	0	0	0
Cold Flashes	12	0	0	0	11	0	0	0	11	1	0	0	10	0	0	0	10	0	0	0	12	0	0	0
Dizziness	6	1	4	1	2	6	2	1	4	3	5	0	8	2	0	0	9	1	0	0	12	0	0	0
Tunnel Vision	8	1	3	0	8	1	2	0	10	2	0	0	10	0	0	0	10	0	0	0	12	0	0	0
Loss of Concentration	5	2	3	2	7	1	3	0	3	7	2	0	9	1	0	0	9	1	0	0	12	0	0	0
Light Dimming	10	1	0	1	9	1	0	1	11	0	1	0	10	0	0	0	10	0	0	0	12	0	0	0
Euphoria	4	0	5	3	4	3	3	1	6	0	5	1	6	4	0	0	9	1	0	0	12	0	0	0
Loss of Coordination	6	2	3	1	6	2	3	0	8	3	1	0	9	1	0	0	10	0	0	0	12	0	0	0
Headache	10	1	1	0	8	1	2	0	11	1	0	0	10	0	0	0	10	0	0	0	11	1	0	0
Fatigue	12	0	0	0	11	0	0	0	12	0	0	0	10	0	0	0	10	0	0	0	12	0	0	0
Breathlessness	9	1	2	0	6	4	1	0	9	1	2	0	10	0	0	0	10	0	0	0	12	0	0	0
Blurred Vision	6	2	4	0	9	0	1	1	10	2	0	0	10	0	0	0	10	0	0	0	12	0	0	0
Nausea	11	0	1	0	11	0	0	0	11	1	0	0	10	0	0	0	10	0	0	0	12	0	0	0
Apprehension	9	1	2	0	9	1	1	0	7	5	0	0	9	1	0	0	8	2	0	0	11	1	0	0
Other Symptoms Reported																								
Double Vision		1									1	1												
Time Speeded Up		1																						
Confusion				1																				
Tasted H_2O_2		1								1		1		1										
Spots Before Eyes																								
Agitation																								
Ringing in Ears								1																
Loss of Control										1														
Crossed Vision														1										

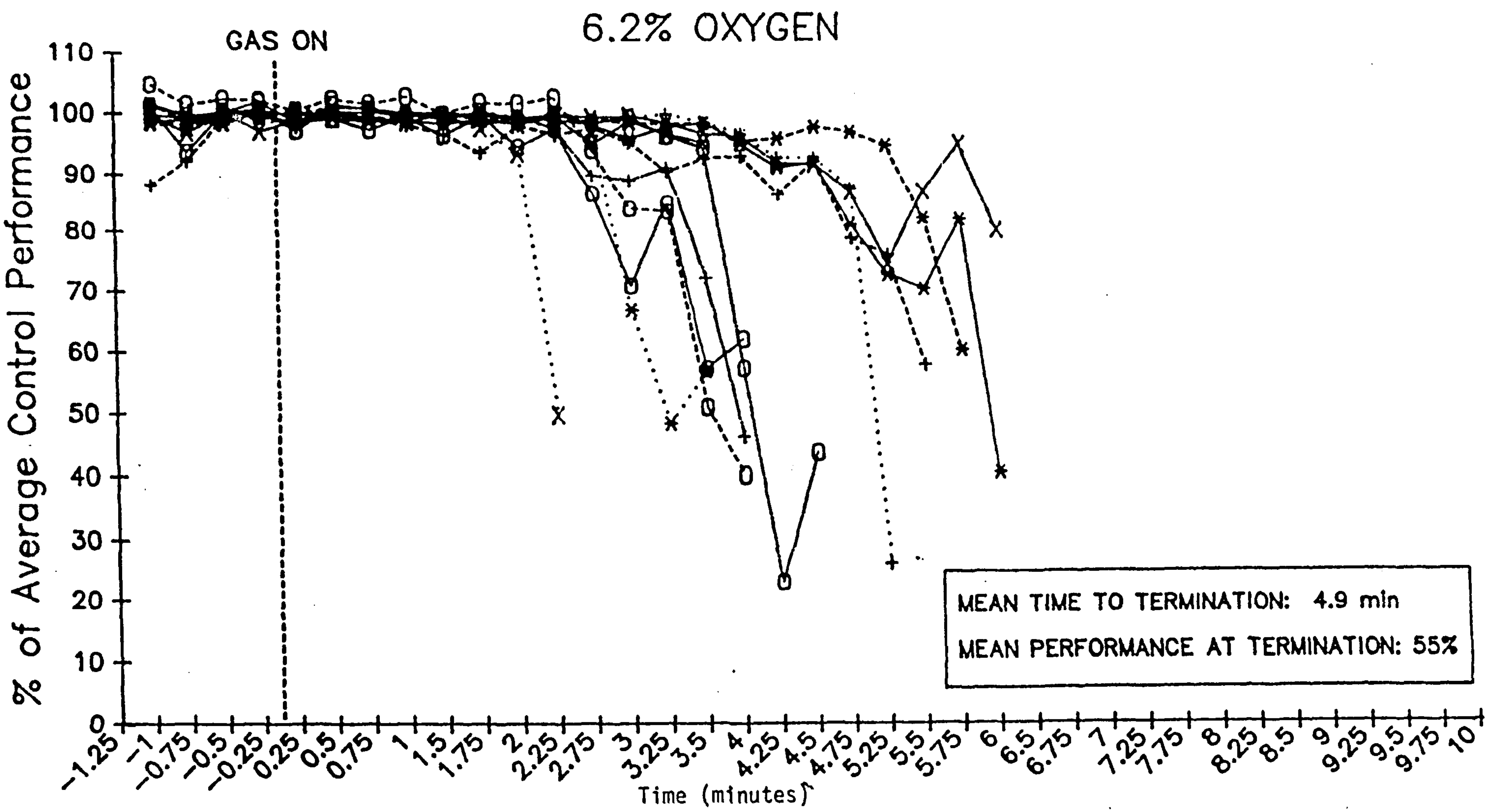

FIGURE 1

TRACKING PERFORMANCE FOR 6.20% O_2 MIXTURE (N=12)

Missing time intervals were subject rest periods during which tracking was not performed and scores not obtained.

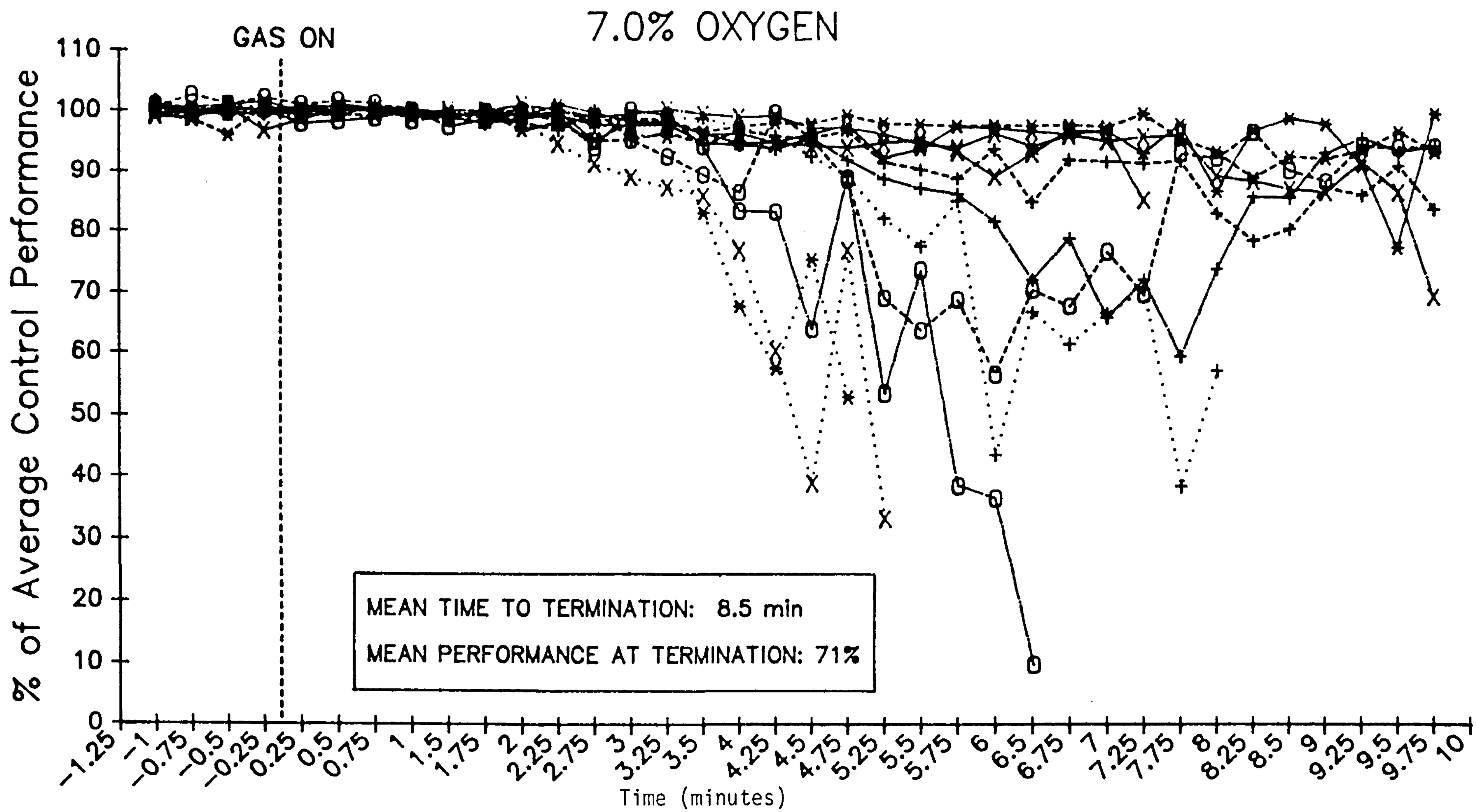

FIGURE 2

TRACKING PERFORMANCE FOR 7.00% O_2 MIXTURE (N=11)

Missing time intervals were subject rest periods during which tracking was not performed and scores not obtained.

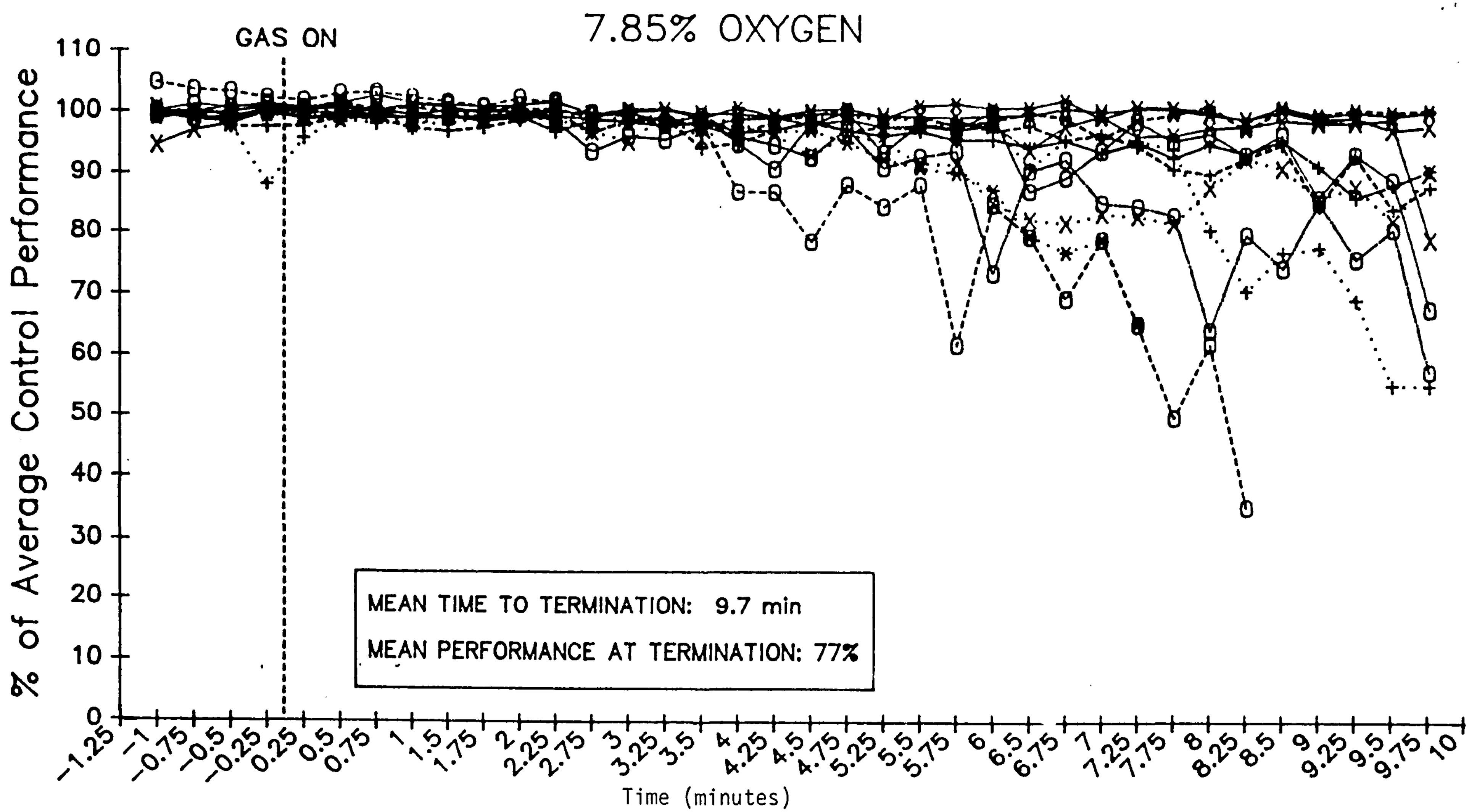

FIGURE 3

TRACKING PERFORMANCE FOR 7.85% O_2 MIXTURE (N=12)

Missing time intervals were subject rest periods during which tracking was not performed and scores not obtained.

only 55% for the 6.2% O_2 mixture. No decrease in tracking performance occurred while breathing either the 11.84% O_2 or the 14.14% O_2 mixtures.

Values for percent oxygen saturation, end tidal carbon dioxide, respiratory rate, and heart rate are shown in Figure 4. For all five reduced oxygen gas mixtures, the percent oxygen saturation returned to pretest levels by the end of the one-minute recovery period breathing 100% oxygen. End tidal carbon dioxide values did not fully return to pretest levels by the end of the recovery period. Although respiratory rates increased during the test sessions for four of the six gas mixtures, they dropped to levels below the pretest values by the end of the one-minute recovery period for all six test mixtures. Heart rate increased during the test sessions for the three lowest oxygen mixtures, remained unchanged for the highest three oxygen mixtures, and decreased to levels below pretest values by the end of the recovery period for four of the six mixtures.

IV. DISCUSSION

This study examined the effects various hypoxic mixtures had on human subjects. The results were examined for two possible applications. The first involved deep sea diving. The second proposes a safer alternative than hypobaric exposure to demonstrate hypoxia to flight crew personnel.

A. DEEP SEA DIVING APPLICATION

1. Background

Deep sea diving with mixed gas helium-oxygen requires careful attention to the oxygen partial pressure for a given duration. The partial pressure is determined by multiplying the oxygen volume fraction by the ambient pressure. A 16% volume fraction at sea level or 1 ATA has an oxygen partial pressure of 0.16 ATA. At 33 feet of sea water (FSW) or 2 ATA, the partial pressure of oxygen is 0.32 ATA. Partial pressures of oxygen as low as 1 ATA are limited to specified durations to prevent central nervous system (CNS) toxicity (4). This condition manifests with a variety of symptoms including convulsion and unconsciousness. Both are potentially fatal conditions if they occur while diving. As a matter of safe diving practice, a breathing gas mixture's volume fraction of oxygen is selected based on what the partial pressure of oxygen will be at the deepest

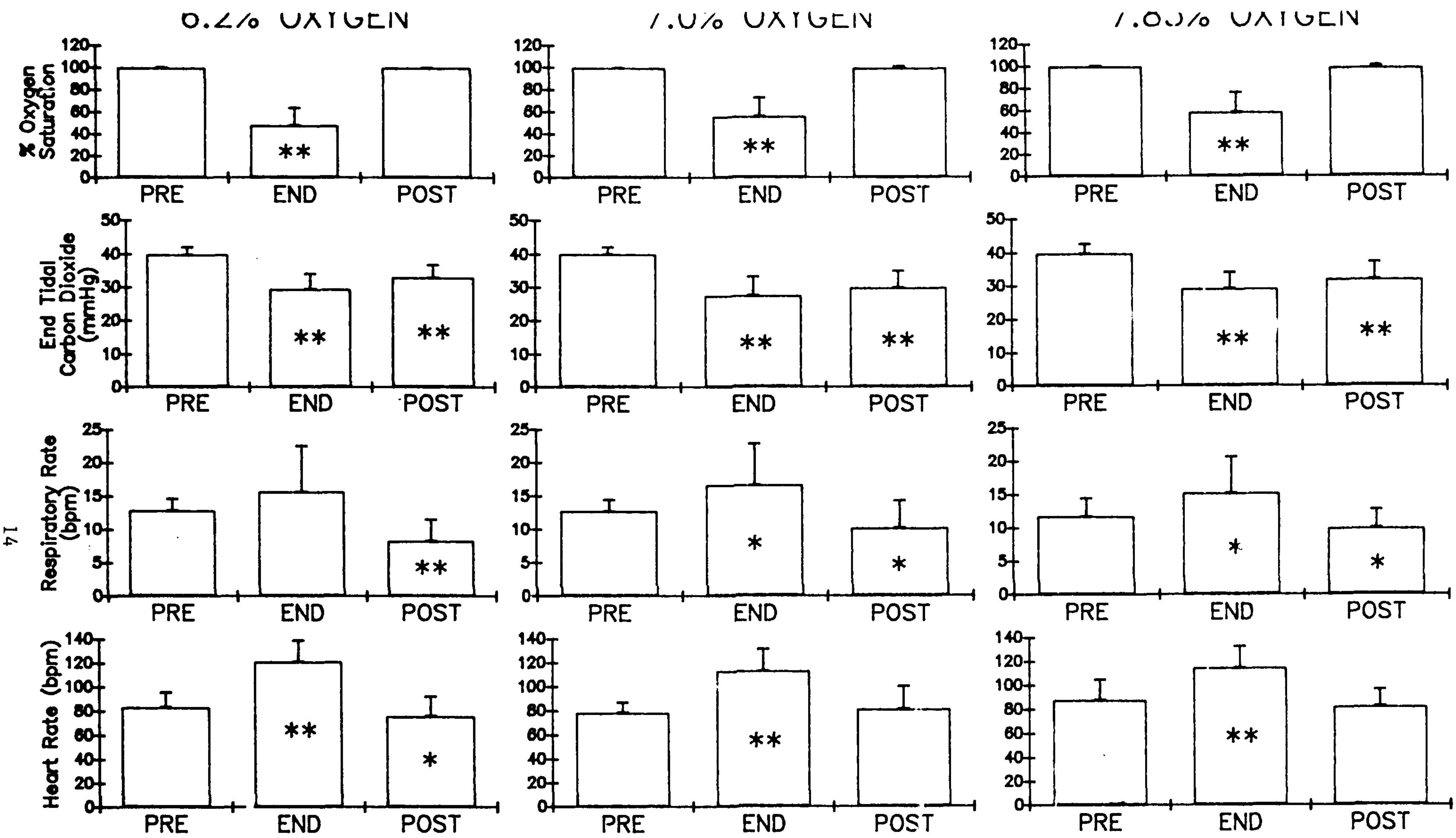

FIGURE 4

PHYSIOLOGIC DATA

PRE = Mean values for 1.25 min period breathing air before start of test
END = Mean for last values obtained before test termination
POST = Mean values at 1.0 min mark of recovery period

* $p < .05$; ** $p < .01$ Compared to PRE value with one-tailed, paired t-test

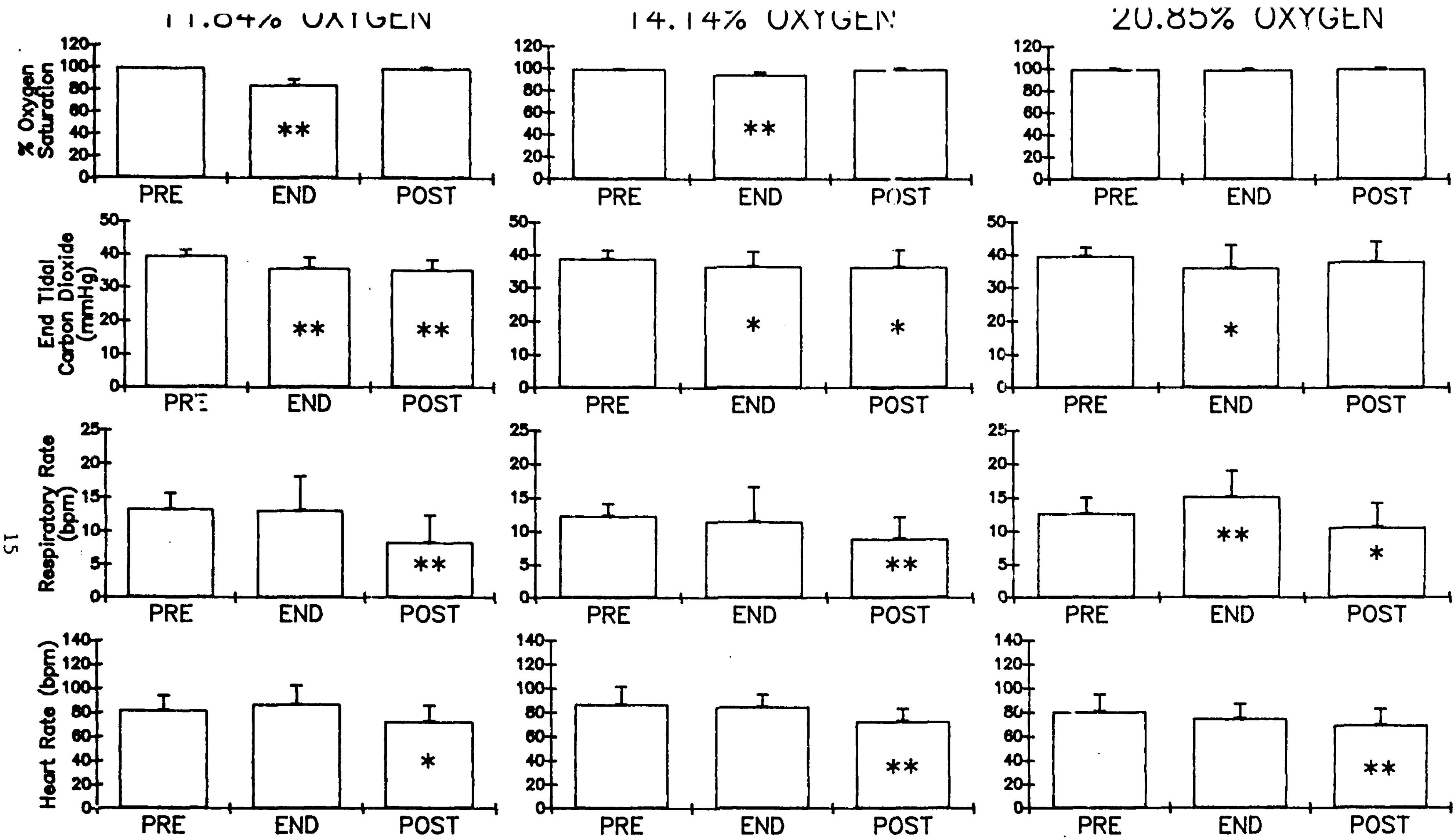

FIGURE 4 (CON'T)

PHYSIOLOGIC DATA

PRE = Mean values for 1.25 min period breathing air before start of test
END = Mean for last values obtained before test termination
POST = Mean values at 1.0 min mark of recovery period

* $p < .05$; ** $p < .01$ Compared to PRE value with one-tailed, paired t-test

working depth. This partial pressure of oxygen is not to exceed 1.6 ATA at depth. Unfortunately, the volume fraction of oxygen required to conform to a maximum 1.6 ATA partial pressure when diving below 218 FSW is lower than the 21% oxygen volume fraction found in air. Hypoxia may result if minimum partial pressures of oxygen are not maintained. Current guidelines require a mixture of at least 16% oxygen volume fraction at sea level to prevent hypoxia. Any further decrease below 16% oxygen volume fraction, in order to dive deeper or longer, requires shifting to that mixture at a depth of 50 fsw [4]. The ambient pressure at 50 fsw is 2.5 ATA and therefore raises the partial pressure of oxygen by 2.5 times that seen on the surface. It is evident that the diving supervisor must maintain the partial pressure of oxygen throughout the dive profile between the limits for hypoxia and CNS oxygen toxicity. The lowest allowable volume fraction of oxygen in the breathing mix allows the greatest latitude in planning the depth or duration of a dive. It also minimizes or eliminates the gas switches required during the dive. This study examined the possibility of reducing the oxygen volume fraction below the current minimum of 16% on the surface.

2. <u>Lowering the 16% Volume Fraction Requirement for Navy Diving</u>

This issue can be divided into two questions. The first is whether a gas mixture with an oxygen partial pressure less than 0.16 ATA can be used safely at depth and the second is whether less than 16% oxygen volume fraction or 0.16 ATA can be used at the surface.

a. <u>Use of 0.16 ATA at Depth</u>. Using an oxygen partial pressure less than 0.16 ATA at depth is an academic question primarily. Three factors support present limitations without further reduction. They are:

(1) <u>Decompression Stress Is Increased</u>. Even disregarding the inherent benefits of oxygen during decompression, minimizing the partial pressure of oxygen in the breathing mix raises the partial pressure of inert gas. By raising the partial pressure of inert gas, the decompression stress is increased for any given depth. This results in a greater risk of DCS, which requires increased decompression time for the diver. Besides decreasing the fraction of in-water time for useful work, increased decompression increases thermal stress during in-water decompression.

(2) Normoxic Hypoxia: Chouteau Effect. The second factor is the Chouteau effect. This phenomenon was reported by Chouteau where his test animals became hypoxic when breathing normoxic partial pressures of oxygen (0.21 ATA) at deep depths. The symptoms abated when additional oxygen was added to the breathing mixture [5]. Edmonds ascribes this phenomenon to an alveolar-arterial diffusion abnormality [6]. Flynn, et al., call the phenomenon stratified inhomogenity [7]. Both increased gas density and the hydrostatic pressure effects have been implicated as possible factors. This occurs at deeper depths and would be a factor in atmospheres where the partial pressure of oxygen is held constant, such as saturation diving. Saturation diving practice maintains a partial pressure greater than 0.4 ATA and symptoms of hypoxia have not been reported.

(3) Hypoxia with Exercise (Work). Subjects exercising while breathing hypoxic mixtures increased the level of hypoxia seen during rest. Significant psychomotor performance decrement was demonstrated by Knight when his subjects exercised at 140 watts while breathing 12% volume fraction of oxygen at 1 ATA [8]. This decrement would be unacceptable for underwater work which can attain the exercise levels studied by Knight.

This study was conducted at 1 ATA with resting divers seated for psychomotor testing. The conditions were considerably less stressful than a working diver breathing a denser gas mixture at depth. Even under the less strenuous test conditions, the results do not indicate the need for further study to relax current minimum oxygen limits at depth since oxygen desaturation was detected between 12-16% oxygen volume fractions.

b. Relaxation of the 16% Oxygen Volume Fraction. The results of this study better reflect the diver seated on the dive station at 1 ATA or at sea level. A range of oxygen partial pressures used in mixed gas diving operations was examined. Mixtures closely approximating 12% and 14% oxygen volume fractions revealed a decrement in the oxygen saturation but no change in psychomotor testing. The falls in oxygen saturation at both 11.84% and 14.14% support the current 16% volume fraction minimum on the surface for surface supplied diving operations [4]. At both of these oxygen

concentrations, the divers completed the full series of psychomotor testing without a performance decrement. However, Knight has shown that exercise imposes additional oxygen demands on the body with an ensuing hypoxemia at this same mixture [8]. The declines in oxygen saturation demonstrated in this study may be an early indication that further oxygen demands during exercise would evoke clinical symptoms of hypoxia. These oxygen demands could be seen on a dive station, since a fully dressed deep sea HeO_2 diver experiences moderate levels of exertion when entering and exiting the water. Although on most occasions the diver will be leaving the water on 100% O_2 after a successful HeO_2 dive, there are many occasions when the dive would be aborted during initial descent and no shift to O_2 would have occurred. This level of exertion would be expected to increase his oxygen demands during these two phases of the dive which occur at or near 1 atmosphere of ambient pressure. Consequently, it is at this point that the inspired partial pressure of oxygen will be at its lowest for a given oxygen volume percent. The combination of physical exertion and an hypoxic breathing mix could result in symptoms such as lightheadedness, confusion, or unconsciousness. These could be construed as decompression sickness or gas embolism if they are present on exiting the water after a dive.

Consequently, no reduction of the currently used minimum of 16% oxygen volume fraction on the surface is recommended.

B. HYPOXIC BREATHING MIXTURE AT 1 ATMOSPHERE AS AN ALTERNATIVE TO HYPOBARIC EXPOSURE

For a reduced oxygen gas mixture to have practical hypoxia training application, it must induce a significant level of hypoxia in a student in a relatively short period of time without exposing the student to serious health risks. While the 11.84% O_2 and 14.14% O_2 mixtures lowered subject's percent oxygen saturation values, this was insufficient to decrease tracking performance scores. These two gas mixtures would have no practical hypoxia training application. The 7.00% O_2 and 7.85% O_2 mixtures were successful in producing a level of hypoxia sufficient to lower subject's tracking performance scores to 71% and 77% of control scores, respectively. However, the mean time to test termination was 512 seconds (8.5 min) for the 7.00% O_2 mixture and 583 seconds (9.7 min) for the 7.85% O_2 mixture. In addition, 6 of 11 subjects for the 7.00% O_2 mixture and 10 of the 12

subjects for the 7.85% O_2 mixture were still performing the tracking task at the automatic stopping point of 600 seconds. Because ever-expanding training curricula make training time increasingly critical, these two gas mixtures do not have good hypoxia training application due to the excessive amount of time required to induce symptoms and the minimal degree of performance decrement produced. The rapid loss of performance also better simulates the conditions that develop in a true hypobaric exposure. The 6.20% O_2 mixture lowered tracking performance scores to 55% of control values and accomplished this in a mean time to test termination of just 293 seconds (4.9 min). None of the 12 subjects reached the automatic stop point. Not only was tracking performance dramatically affected by this gas mixture, but it also produced very recognizable subjective hypoxia symptoms. Thirteen of the fifteen symptoms presented on the post-test questionnaire plus three additional symptoms were reported as having been experienced by the subjects. Other investigators have demonstrated that the type of subjective symptom and its severity is the same regardless of whether the hypoxic state is produced by simulated altitude, as in a low pressure chamber, or by an equivalent oxygen-nitrogen gas mixture [9]. While the 6.20% O_2 mixture produced a very pronounced hypoxic state, subjects recovered very rapidly with no apparent diminished capacities. Immediately following the one-minute recovery period breathing 100% O_2, each subject stood up, walked across the room, sat down at a table, and proceeded to fill out the post-test questionnaire. No difficulties were observed. The 6.20% O_2 gas mixture does induce a significant level of hypoxia in a short period of time without producing a serious health risk. It therefore has good hypoxia training application.

Since this study supports previous findings that hypoxic exposures at 1 atmosphere adequately simulate the hypoxia experienced in the hypobaric chamber, the risk of decompression sickness associated with hypobaric exposures requires careful consideration.

Decompression sickness (DCS) or bends is a serious neurologic condition that requires a decreased ambient pressure for a given gas mixture. It is an occupational hazard of those who must breathe compressed gas at depth before returning to the surface such as divers and those who rapidly ascend from sea level to altitude such as pilots or astronauts. Rudge has reported a case of DCS developing at an elevation of 8,000 feet [10]. No report can be found that details a benefit or resistance to DCS by

prophylactically causing DCS or "bending" the individual in a chamber prior to the operational exposure. The long term disabilities from DCS that potentially result would further make this practice unwarranted. In addition, the expenditure in manpower and facilities needed for adequate timely treatment requires assessment. This practice can cause DCS that could result in the permanent disability and disqualification of the diver, pilot, or astronaut. These highly trained individuals are the end product of considerable time and resources to achieve their qualifications. Despite the serious consequences of DCS, the following sobering statistics exist. Of the 528 DCS cases treated by the U.S. Air Force at Fort Sam Houston between 1 January 1977 until 31 December 1986, 96% of the cases (507) resulted from altitude exposures in hypobaric chambers. Only 4% (21 cases) were from in-flight exposure (Wein) [11]. Many of these hypobaric exposures were administered without a recompression chamber available for treatment. Green, et al., have shown that prompt hyperbaric oxygen treatment results in favorable outcome, if administered shortly after presentation of symptoms [12]. Wein has shown that prompt treatment is essential in altitude DCS [11].

Since hypoxic simulation can be achieved at 1 atmosphere and little other major benefit can be achieved in rapid hypobaric chamber exposures, this present practice should be replaced at the earliest opportunity.

V. CONCLUSIONS

1. A 93.80%N_2, 6.20%O_2 gas mixture at 1 atmosphere has practical application for use as an alternative method of inducing hypoxia during naval aviation physiology training. In a short period of time, it induced a significant hypoxic state from which subjects quickly and completely recovered.

2. All future routine hypobaric chamber exposures should be reevaluated. Procedures that use hypoxic gas mixtures at 1 atmosphere should be used for hypoxia training. The requirement for trained personnel to act as safety observers remains as important.

3. If manned hypobaric chamber exposure is required, a human subject use committee should review the need in each case. It should also be conducted in the vicinity

of a hyperbaric treatment facility capable of treating all the subjects on at least a U.S. Navy treatment table 6 with full extensions.

4. No reduction in the currently allowed 16% oxygen volume fraction is recommended in diving gas mixtures while the diver is on the surface. Further studies are required to evaluate other than resting conditions.

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